Deep-sea corals: out of sight, but no longer out of mind

Santi Roberts and Michael Hirshfield

Two-thirds of all known coral species live in waters that are deep, dark, and cold. Yet due to the difficulty of researching them in their natural environment, their biology and ecology are poorly understood. Deep-sea coral communities provide habitat for many vertebrate and invertebrate species, including some commercially important fish and crustacean populations. Some have levels of biological diversity comparable to shallow-water reefs. They are also highly susceptible to disturbance from many of our deep-sea activities. Bottom trawling in particular has caused considerable destruction of these communities around the world. Due to their extreme longevity and slow growth, recovery is likely to be in the order of decades or even centuries. We provide an overview of deepwater coral biology and ecology, identify the more manageable threats, and suggest recommendations to mitigate further loss.

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The existence of deep-sea corals was first documented over 200 years ago, although most of what we now know about them has been learned in the past few decades. Since the development of manned and unmanned submersible vehicles, scientists have finally been able to study these corals in their natural environment.

In many ways, deep-sea corals are similar to their shallow-water relatives. They show great diversity in size, shape, and color, from white cups the size of fingertips to crimson trees 3 m tall. Some are stony and hard to the touch, while others are soft and sway with the current. A few species build large reef structures reaching many meters from the seafloor (Rogers 1999), several build smaller colonies, and still others are solitary. Most seem to be part of larger communities of sponges, sea anemones, fish, shellfish, and a host of other species.

Unlike most tropical and subtropical corals, however, deep-sea corals do not form symbiotic relationships with algae, and so they do not obtain any energy directly from sunlight. Instead, they capture microscopic organisms and detritus from the surrounding water. Without having to depend on algae, they can live far outside the reach of the sun's rays, and have been found up to 6 km below the ocean's surface. They can also survive much lower temperatures – as cold as 30° F – and so are found as far north as the Norwegian Sea and as far south as the Ross Sea in Antarctica (Stanley and Cairns 1988).

> **In a nutshell:**
> - Deepwater corals are found in all oceans of the world, generally on the edges of continental shelves and on seamounts
> - Recent research has demonstrated their ecological and economic importance, and documented their widespread damage due to destructive trawling practices
> - The only real way to protect these areas is to identify where they are and close those areas to destructive bottom-fishing gear

Oceana, 2501 M Street NW #300, Washington, DC 20037 (sroberts@oceana.org)

Corals, whether of the deep- or shallow-water varieties, belong to two classes within the phylum Cnidaria. Those in the Class Anthozoa can be further divided into the subclasses Hexacorallia and Octocorallia. Hexacorals include the Scleractinia, which build the hard, calcium-based reefs most commonly associated with corals, and the Antipatharia, or "black corals", which form a tree- or stick-like structure adorned with knobs or spines. The octocorals include soft corals, which are generally small and do not build hard skeletons, and the gorgonian sea fans, which have a flexible internal skeleton, allowing them to take on tree- or bush-like forms of considerable size. The second class of corals is the Hydrozoa, which have massive and fairly brittle calcium carbonate skeletons (Etnoyer and Morgan 2003; Figure 1).

We know little about the distribution of the vast majority of deepwater corals. Some are distributed worldwide, others are found in several areas, and yet others are restricted to only a few locations or even a single place (Rogers 1999; Gubbay 2002; Cairns SD pers comm). Most of those discovered to date seem to be on the edges of the continental shelf or on underwater islands called seamounts.

About 20 of the 703 known species of deep-sea stony corals build reef structures (Cairns SD pers comm). *Lophelia pertusa* is a reef-forming coral that provides a highly complex habitat supporting as diverse an array of life as some shallow-water reef communities (Rogers 1999). Larger *L pertusa* reefs, estimated to grow at 4–25 mm a year, are thought to be many thousands of years old (Rogers 1999). Most living reefs are found at depths

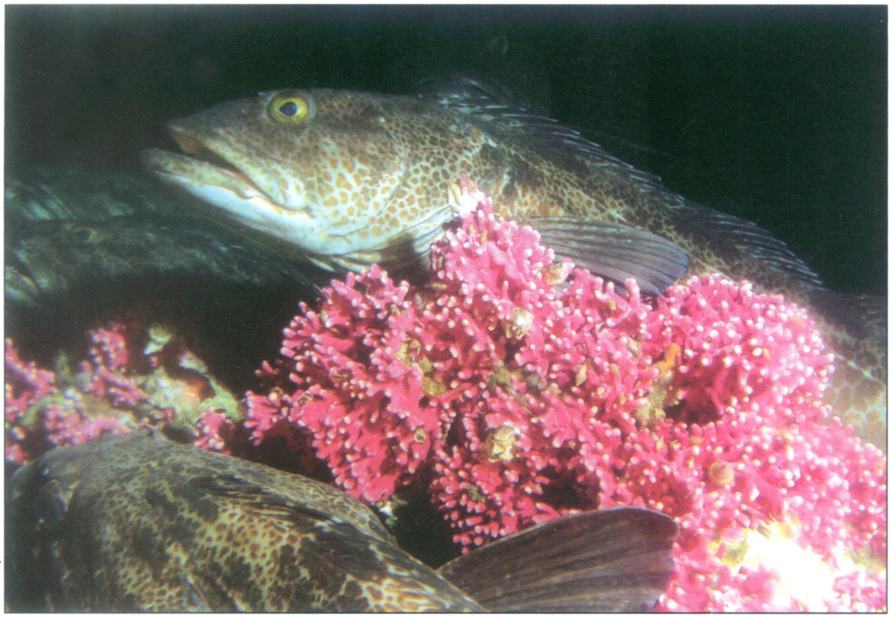

Figure 1. Lingcod and hydrocoral off Adak Island in the Aleutian Islands, Alaska.

of 200–1000 m, in all oceans except the polar regions (Fossa *et al.* 2002). One of the largest *L pertusa* reefs discovered is about 300 m deep, in the waters off Norway. It is more than 13 km long and about a quarter of a mile wide, and some parts reach as high as 30 m off the seafloor (Freiwald 2002; Figure 2). Off the coast of the US, *L pertusa* mounds have been discovered in deep waters in the Gulf of Mexico (Schroeder *et al.* in press) and off the East Coast from southern Florida to North Carolina (Reed 2002a; Sulak KJ pers comm).

One deepwater form of the ivory tree coral (*Oculina varicosa*) builds extensive reefs similar in size, shape, and structure to *L pertusa* (Reed 2002a). The deepwater *O varicosa* reefs found off the southeastern US coast are probably unique in the world, although non-reef-building forms of the same species are known to occur in the Caribbean, the Bahamas, and the Gulf of Mexico (Reed 2002b). These reefs are known as the Oculina Banks, and stretch for over 167 km along the central-eastern Florida shelf edge at a depth of 70–100 m (Reed 2002b). Ivory tree coral grows at an average rate of 16 mm per year at 80 m depth (Reed 1981), and is estimated to be up to 1500 years old (Reed 2002a).

The gorgonian corals *Primnoa resedaeformis* and *Paragorgia arborea*, more commonly known as red tree and bubblegum coral, can form great branching trees that stand some meters above the seabed. Red tree corals 2 m tall and 7 m wide have been observed from submersibles (Krieger and Wing 2002), and fishermen have reported bubblegum trees over 3 m tall and 30 cm thick at the base (Breeze 1997). Both species are found throughout the North Atlantic and North Pacific oceans down to at least 750 m below the surface (Breeze 1997; MacIsaac *et al.* 2001; Andrews *et al.* 2002). Some bubblegum and red tree colonies can live for hundreds of years (Risk *et al.* 1998; Andrews *et al.* 2002; Tracey *et al.* 2003; Figure 3).

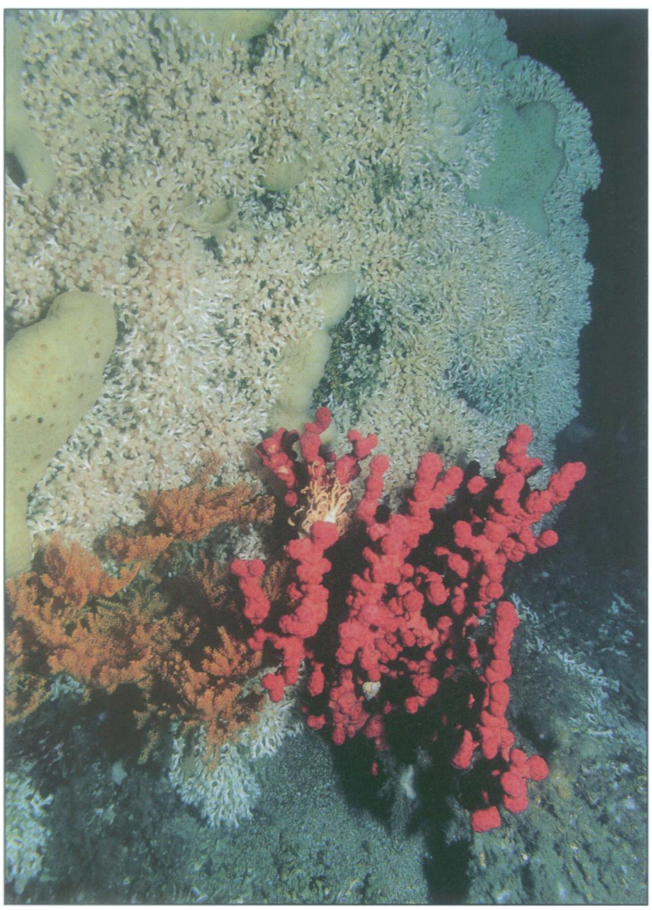

Figure 2. Paragorgia arborea *(bubblegum coral) growing on* Lophelia *reef within diving depth in Norwegian waters, home to the shallowest known* Lophelia *reefs in the world.*

Ecological importance

Deep-sea coral communities may be composed of many types of coral and other living habitat. It is estimated that more than a hundred deep-sea coral and sponge species live in the North Pacific off Alaska (Stone RS pers comm), at least 34 of which are corals (Heifetz 2000; Figure 4). Furthermore, although thousands of different types of deep-sea coral have been described, researchers estimate that roughly 800 species of stony corals alone have yet to be discovered (Cairns 1999), in addition to much of their associated fauna. Koslow *et al.* (2001) recorded dense and diverse invertebrate communities on Tasmanian sea-mounts dominated by suspension feeders, including reef-forming and gorgonian corals, hydroids, and sponges. They estimate that

24–43% of these species are new to science, and 16–33% are endemic to the seamount environment (Figure 4).

The coral *L pertusa* provides habitat for animals such as sponges, anemones, bryozoans, gorgonians, worms, fish, molluscs, and crustaceans (Rogers 1999). Roberts *et al.* (in press) have recorded a total of more than 1300 species living on or in *L pertusa* reefs in the northeast Atlantic. The variety of life on these reefs is about three times higher than on surrounding soft bottoms (Husebo 2002). The Oculina Banks also support an exceedingly high diversity of fish, shellfish, starfish, sponges, and other organisms, similar to that found on tropical coral reefs (Reed 2002b).

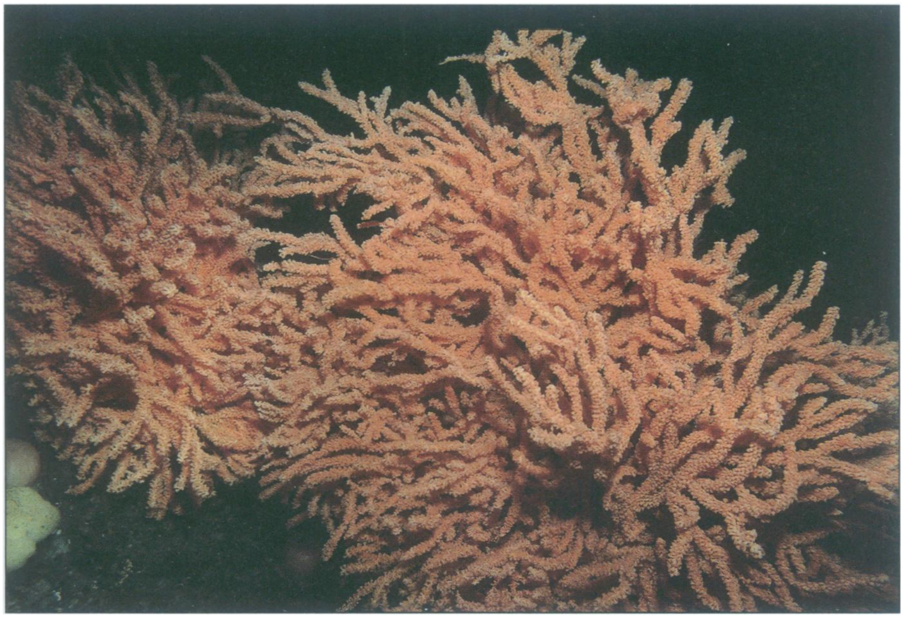

Figure 3. Primnoa resedaeformis, *better known as red tree coral or sea corn, within diving depth in Norwegian waters.*

Numerous animal species are known to use red tree corals as both food and habitat. Economically important rockfish, shrimp, and crabs hide among the branches, seeking protection. Crinoids, basket stars, anemones, and sponges attach themselves to dead branches so they may better filter food from the currents. Other animals, such as sea stars and snails, feed directly on the corals themselves (Krieger and Wing 2002).

■ Commercial importance

Deep-sea corals, sponges, and other habitat-forming organisms provide protection from currents and predators, nurseries for young fish, and feeding, breeding, and spawning areas for numerous fish and shellfish species. Rockfish, Atka mackerel, walleye pollock, Pacific cod, sablefish, flatfish, crabs, and other economically important species in the North Pacific inhabit these areas (Krieger and Wing 2002). During submersible dives in the Gulf of Alaska between 1989 and 1997, 85% of the large rockfish recorded were observed seeking protection under red tree corals (Krieger and Wing 2002). Flatfish, walleye pollock, and Pacific cod appear to be more commonly caught around soft corals (Heifetz 2000).

Fish aggregate on deep-sea reefs (Husebo 2002). Dense schools of gravid redfish have been observed on *L pertusa* reefs off the coast of Norway (Fossa *et al.* 2002), suggesting that the reefs are breeding or nursery areas for some species (Baker *et al.* 2001). The dense and diverse Oculina Banks community supports large numbers of fish, forming breeding grounds for gag and scamp grouper, nursery grounds for young snowy grouper, and feeding grounds for many other economically valuable fish, including bass, jacks, snappers, porgies, sharks, and other groupers (Reed 2002b; Figure 5).

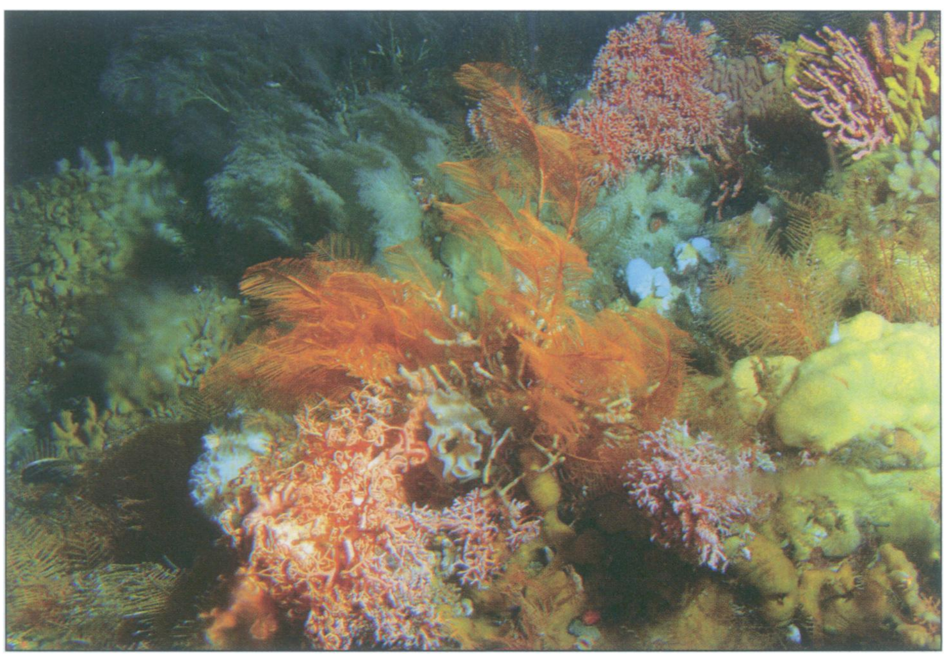

Figure 4. *Colorful deep-sea habitat off Adak Island in the Aleutian Islands, at less than 300 m depth (2001).*

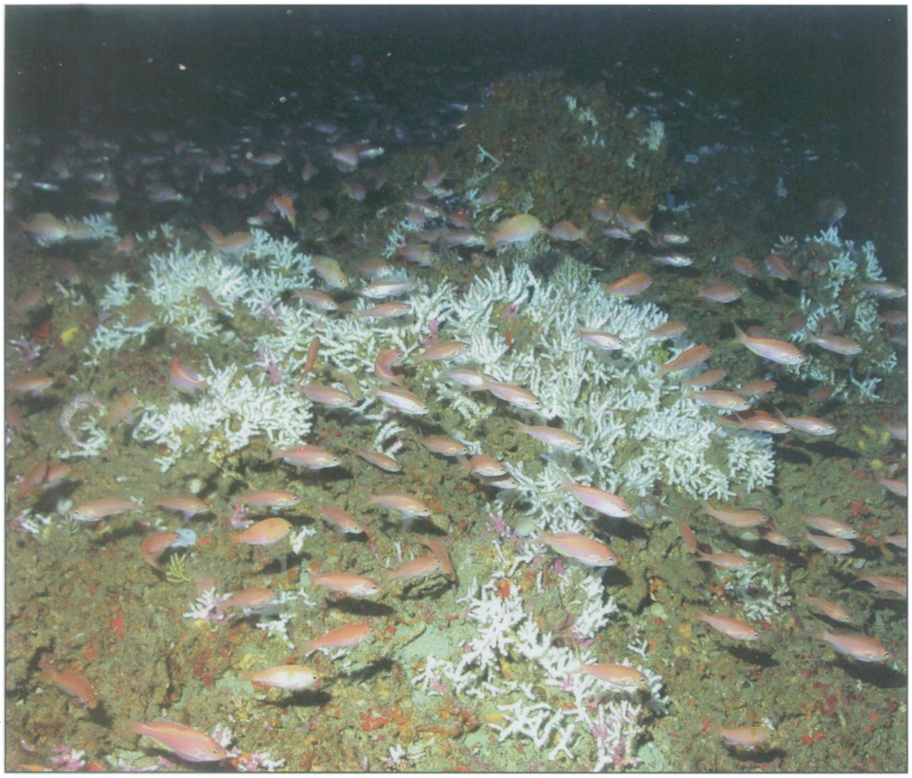

Figure 5. School of anthiid reef fish over Oculina *colony in the* Oculina *Banks, Florida, at about 75–100 m depth.*

Anecdotal evidence that corals are important to fisheries includes fishermen's accounts that areas with deep-sea corals are good fishing grounds (Fossa *et al.* 2002; Breeze 1997). When fishing around deepwater coral habitat, longline fishermen set their gear for different species of fish, depending on the types of coral in that area. For example, when fishing around *Gersemia rubiformis*, a soft coral known as "strawberries", longline fishermen from Nova Scotia set their lines for haddock, but they target cod and halibut when around bubblegum tree coral (Lees 2002).

Studies support fishermen's assertions that the disappearance of corals influences the fish distribution in the area. Fossa *et al.* (2002) found that longline catches of rockfish may be six times higher, and for ling and tusk two to three times higher, on *L pertusa* reefs in Norway compared to non-reef areas. Krieger and Wing (2002) concluded that the removal or damage of red tree corals in Alaskan waters could have long-term effects on associated faunal communities, including economically important species.

Deep-sea coral and sponge communities are also a largely untapped resource of natural products with enormous potential as pharmaceuticals, nutritional supplements, enzymes, pesticides, cosmetics, and other commercial products (Bruckner 2002). Compounds found in the deep-sea sponges *Discodermia* spp and *Lissodendoryx* sp, for example, have been found to be potent immunosuppressive and anticancer agents (NRC 1999).

■ Manageable threats to deep-sea coral communities

There is evidence that our exploitation of the deep ocean is causing substantial damage to deep-sea coral communities. In Norwegian waters, for example, Fossa *et al.* (2002) estimate that between one-third and one-half of the deepwater reefs have been damaged or destroyed by trawling. Considerable damage to deepwater coral communities has been recorded off both coasts of North America, off Europe from Scandinavia to northern Spain, and on seamounts near Australia and New Zealand (Figure 6).

Bottom trawling, in which a large bag-shaped net is dragged along the seafloor to catch fish, shrimp, and crabs is the most widespread human threat to deep-sea coral and sponge communities. Some 40% of the world's trawling grounds are now deeper than the edge of the continental shelf (Burke *et al.* 2001), on the slopes and in the canyons of the continental margins, and on seamounts. In Alaskan waters alone, the National Marine Fisheries Service estimates over one million pounds of corals and sponges were removed from the seafloor annually between 1997 and 1999 by commercial fishing – roughly 90% by bottom trawlers (NMFS 2003). These estimates may grossly underestimate the actual level of damage, as many of the corals and sponges are crushed and not pulled to the surface to be counted by observers.

With the advent of more powerful engines, improved mapping, navigational and fish-finding electronics, and stronger, lighter synthetic materials, trawlers can now fish in deeper and deeper waters (Koslow *et al.* 2001). Deep-sea trawlers can operate to depths of at least 2 km (Freiwald 2002), and can fish in deep-sea canyons and over rough seafloor that they once avoided because of the damage to their nets (Koslow *et al.* 2001).

The mouth of a trawl net is held open by two doors which, in the case of bottom trawls, also help to keep the net on the seafloor (Roberts 2002). Deeper trawling requires heavier trawl doors – one US company markets trawl doors called "Canyonbusters", the heaviest of which weigh almost 5 tons each (NETSI 2004). On rough bottoms, the net is protected by heavy chafing gear attached to the underside to prevent snagging, as well as a heavy lead cable strung through steel balls or rubber bobbins, some of which are a meter or more in diameter. These technologies, known as "roller gear" or

Courtesy of JH Fossa, Norwegian Institute of Marine Research

Figure 6. *Furrows or scars in the seabed are unmistakable evidence of trawling. These pictures are from Norwegian waters, where between one-third and one-half of* Lophelia pertusa *reefs have been damaged by trawling.*

"rockhoppers", are capable of moving 18-ton rocks (Risk *et al.* 1998), and so can cause severe damage to corals and sponges with even a single pass (Krieger 2001). Prior to the development of these technologies, trawl fishermen would even "trim the trees", intentionally knocking down corals by towing a heavy chain between two vessels (Breeze 1997; Figure 7).

The US National Academy of Sciences recently concluded that stable, living habitats such as coral and sponge communities are among the habitats most heavily damaged and the slowest to recover from trawling (NRC 2002). The effects of trawling on such communities include directly killing corals by crushing or ripping from the seafloor, breaking up reef structure, and burying corals through increased sedimentation. Wounds in coral tissue and infection cause additional deaths in those that are not killed outright (Rogers 1999; Fossa *et al.* 2002).

Koslow and Gowlet-Holmes (1998) found substantial damage to corals on Tasmanian seamounts as a direct result of trawling for fish such as orange roughy and oreos. Heavy fishing had effectively removed all reef habitat from some seamounts; the most heavily fished were over 90% bare rock. The authors note the "virtually complete loss of this [coral] community...is consistent with other studies of the impact of trawling on reefal or other benthic communities" (Koslow *et al.* 2001). Research in Europe has documented widespread trawling damage to deep-sea coral reefs off Ireland, Scotland, and Norway at depths of 200–1400 m. Photographs document giant trawl scars up to 4 km long. Some coral reefs that have been damaged by trawls are estimated to be approximately 4500 years old (Hall-Spencer *et al.* 2001).

An estimated 90–99% of the extraordinarily diverse and productive *Oculina* reef habitat, found off Atlantic Florida and unique in the world, has been reduced to rubble (Koenig *et al.* in press). Koenig (2001) estimates that only 8-ha of known intact *O varicosa* reef remains, so small a patch that "a trawler could easily destroy it in a single night". An area of roughly 1029 km^2, including the Oculina Banks, is currently closed to bottom fishing, but enforcement is difficult and there is strong evidence that rock shrimp fishermen continue to trawl illegally in the area (Koenig 2001). Trawling thus continues to be the greatest manageable threat to these reefs (Koenig *et al.* in press).

Little long-term research on the recovery rates of deepwater coral and sponge communities from major disturbance has been completed. Yet, with their extreme longevity and slow growth, it seems likely that recovery will be exceedingly slow. Krieger (2001) used a manned submersible in the Gulf of Alaska to observe a trawl path that had pulled up 1 ton of corals 7 years previously. The researchers found that in the 700 m observed, 31 red tree coral colonies had been in the path of the trawl. Even after 7 years, some of the larger colonies that survived the initial trawl were missing 95–99% of their branches, while two smaller colonies were still missing 80% of their individual polyps. No young corals had replaced the dead in the damaged colonies.

Courtesy of D Jones, COHPS and Oceana

Figure 7. The weight of two trawl doors and chain combined can be over 10 tons.

Other fishing gear such as bottom longlines, gillnets, and longline pots can also damage coral communities. Longline fishing gear consists of fishing line that can be many miles long, with attached lines leading to hooks or pots, while gillnets are large rectangular walls of net. Both can be anchored on the bottom with weights of 20–110 kg, and both are sometimes lost at sea, where they continue "ghost fishing", killing marine life long after their intended use. The authors have seen still images taken from videos in which lost fishing gear is caught on, and covers, deep-sea coral in waters off Atlantic Florida, Nova Scotia, Norway, and the UK.

Oil and gas exploration, seabed extraction and mining, and cable laying are potential threats to deep-sea coral communities. All can directly crush and damage corals, and can affect their living conditions by increasing the amount of suspended sediment in the water and altering essential currents and nutrient flows (Gass 2003). Drilling muds and cuttings from oil and gas exploration can be toxic to corals, and are known to kill or alter feeding behavior in shallow water varieties (Baker 2001), although the effects on deepwater corals are unknown. Drill cuttings also settle and build up into piles directly underneath oil platforms, where they can smother and kill corals, sponges, and other organisms that filter the seawater for food (Gass 2003). On the other hand, *L pertusa* colonies have been found growing on offshore oil structures (Bell and Smith 1999; Screoder *et al.* in press), which evidently provide a suitable hard substrate for coral colonization that may not exist naturally in the area.

■ Current management regimes around the world

Very few countries have protections currently in place for deep-sea corals. The following list is not meant to be all-inclusive.

In the Americas, the Oculina Banks off the Atlantic coast of Florida have been protected from bottom fishing since 1984, although illegal fishing continues. A 424 km^2 coral conservation area was created off Nova Scotia, Canada in June 2002, all of which is closed to otter trawling and 90% to longlining. In addition, a submarine canyon with abundant corals off Nova Scotia called "the Gully" is about to be established as a marine protected area.

In Europe, the EU closed the *L pertusa*-rich Darwin Mounds, 185 km northwest of Scotland, to bottom scraping fishing gear in August 2003. The emergency ruling lasts for 6 months, during which the EU will consider permanent closure of the area. An area of about 1000 km^2 at Sula, Norway, was closed in 1999 to protect the extensive *L pertusa* reefs. Since then, four other Norwegian reef areas have been closed to fishing. The latest, Tisler Reef on the Norway/Sweden border, was discovered in the summer of 2002, and closed in June 2003.

In Oceania, 19 seamounts in New Zealand waters have been closed to all forms of trawling, as part of an ongoing research program. The total area amounts to about 40 000 km^2, just over 1% of the country's Exclusive Economic Zone.

■ Recommendations

International and national scientific bodies with jurisdiction over the ocean and the resources within have been tasked with researching deep-sea corals and providing recommendations on how best to manage them. David Griffith, General Secretary of the International Council for the Exploration of the Sea (ICES), provided the following summary: "Towing a heavy trawl net through a cold-water coral reef is a bit like driving a bulldozer through a nature reserve. The only practical way of protecting these reefs is therefore to find out where they are and then prevent boats from trawling over them." (ICES 2002a)

ICES put forth the following recommendations to ensure the best scientific advice on managing *Lophelia* (ICES 2002b):

(1) In order to best tailor advice to actual fishing pressure, ICES member countries and relevant commissions should provide access to detailed, suitably depersonalized data on the location of fishing effort in areas known or likely to contain *Lophelia*
(2) In order to add to knowledge on the distribution of *Lophelia* and trawling impact, ICES member countries and relevant commissions should ensure that bycatch recording schemes include records of *Lophelia*
(3) ICES advises that the only proven method of preventing damage to deepwater biogenic reefs from fishing activities is through spatial closures to towed gear that potentially impacts the bottom

We concur with these recommendations, and suggest they be broadened to include all deep-sea corals and other associated living habitat. We provide the following specific proposals:

- Prohibit any expansion of trawling into currently untrawled areas that potentially contain coral communities
- Close currently trawled areas with known concentrations of corals and sponges
- Close areas that remain open to trawling when corals are subsequently discovered
- Enhance enforcement and establish severe penalties to prevent the deliberate destruction of corals and illegal fishing in already closed areas
- Modify trawling gear, or ban certain kinds completely, so trawling in coral is no longer mechanically possible
- Identify and map the locations of all coral communities
- Fund and initiate research to restore damaged deep-sea coral communities

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